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Comment on "Fractal analysis of ULF electromagnetic emissions in possible association with earthquakes in China" by Ida et al. (2012)

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Abstract. Ida et al. (2012) identified anomalous decreases in the fractal dimension of the vertical (Z) component of the geomagnetic field, which they interpreted as precursors to the China earthquake of 1 September 2003. According to Ida et al. (2012), short-term earthquake prediction seems to be possible only by using electromagnetic phenomena. Here, it is shown that the decreases of the fractal dimension documented by Ida et al. (2012) are not really anomalous, but they are part of the normal geomagnetic activity driven by solar–terrestrial interactions. As a consequence, these fractal dimension decreases are not related to the 1 September 2003 earthquake.

1 Introduction

During the last twenty years, many researchers have investigated ultra-low-frequency (ULF: 0.001–10 Hz) magnetic data searching for seismogenic signals. Several ULF stations were installed in seismic active areas, and many studies have retrospectively documented observations of pre-earthquake magnetic anomalies. On the basis of these reports, some researchers conjectured that one day short-term earthquake prediction using magnetic field observations could become a routine technique. Short-term earthquake prediction is a serious topic. Successful prediction could mitigate the effects of disastrous seismic events. However, short-term deterministic prediction requires reproducible precursors, which should provide information regarding exact location, time, and magnitude of the coming earthquake. Many theories have been proposed to explain the generation of seismogenic ULF magnetic emissions, but none of them can be considered completely satisfactory. Thus, a serious problem concerns the identification of reliable earthquake precursors. Any potential earthquake precursor should be excluded as an anomaly correlated with any other possible source, and it must be also shown to be consistent with other independent geophysical data.

2 Discussion

In recent years, many studies (see, e.g., Campbell, 2009; Masci, 2010, 2011, 2012c; Moldovan et al., 2012; Thomas et al., 2009a, b, 2012a) have shown strong evidence that ionospheric and geomagnetic anomalies claimed to be earthquake precursors were normal magnetic disturbances driven by solar–terrestrial interaction. These papers have examined many controversial reports of earthquake-related signals demonstrating that several methodologies used in previous studies are not appropriate to detect the presence of earthquake precursors (see, e.g., Thomas et al., 2012b). Up to now no strong evidence has been provided to reject the findings of these reviews. Ida et al. (2012) criticized the findings of some of these papers, such as, Campbell (2009) and Thomas et al. (2009a, b), but they did not provide any solid evidence in support of their weak criticism. Among these reviews, there are the studies by Masci (2010, 2013), which demonstrated that the fractal analysis of the geomagnetic field in the ULF band is not a good indicator of an imminent earthquake. On the contrary, Ida et al. (2012) emphasized the importance of the fractal analysis of the ULF band of the geomagnetic field components to identify precursors of earthquakes. They referred to several papers that identified increases in the fractal dimension of the ULF geomagnetic field H component as earthquake precursors. These papers reported a relation between the fractal dimension variations and the occurrence of strong earthquakes such as the 1993 Guam earthquake, the 1996 Biak earthquake, and the 2000 Izu earthquake swarm. Ida et al. (2012) failed to address the review by Masci (2010) that demonstrated that the fractal precursors documented in these papers are signals that are part of normal geomagnetic activity, which therefore cannot be described as earthquake-related anomalies.

In their study, Ida et al. (2012) analyzed magnetic data (1 Hz sampling rate) recorded by a triaxial fluxgate magnetometer system in Kashi, China, during March 2003–December 2006. The first comment concerns the set of data analyzed by Ida et al. (2012). In a previous paper (Ida et al., 2008), the authors conducted a polarization ratio analysis performed by using the same magnetic dataset of Ida et al. (2012). However, the magnetic set of data analyzed by Ida et al. (2008) shows some gaps that, according to the authors, were caused by instrumental problems. Unusually, these gaps disappear in the magnetic dataset reported by Ida et al. (2012).

The ULF power spectrum S of a geomagnetic field component exhibits the power-law behavior $S(f) \propto f^{-\beta}$, where f is the frequency (Füllekrug and Fraser-Smith, 2011). In a $\log S(f) - \log f$ representation, the power spectrum is a line having a slope β, where β is known as the spectral exponent. Power-law behavior is characteristic of fractal time series. The simplest method to calculate β is the "slope method", also called the PSD (power spectral density) method. According to this method, β is obtained from the slope of the best-fit line of the ULF power spectral density in log-log form. If the time series under examination is analogous to the fractional Brownian motion (fBm) model, the spectral index β ranges between 1 and 3, and the corresponding fractal dimension FD is calculated using Berry's equation $\mathrm{FD} = (5 - \beta)/2$ (Masci and Di Persio, 2012). FD represents the dimension of the set of points on the spectrum graph of a time series, in this case a geomagnetic field component, under the assumption that the series is monofractal.

Ida et al. (2012) analyzed local nighttime magnetic data (LT = 02:00–06:00), which were filtered around the frequency of 10 mHz. The authors estimated the fractal dimension of the geomagnetic field components by means of the Higuchi method (Higuchi, 1988). This method provides a stable and precise estimation of the monofractal dimension of a time series (Telesca et al., 1999). During the investigated period of time, several $M_\mathrm{w} > 5$ earthquakes occurred in the surrounding area of Kashi (see Fig. 1 by Ida et al., 2012). The authors documented decreases in the fractal dimension of the geomagnetic field Z component during July–August 2003, January 2004, and June 2005 (see Fig. 2 by Ida et al., 2012). No corresponding decreases were present in the horizontal components H and D. According to Ida

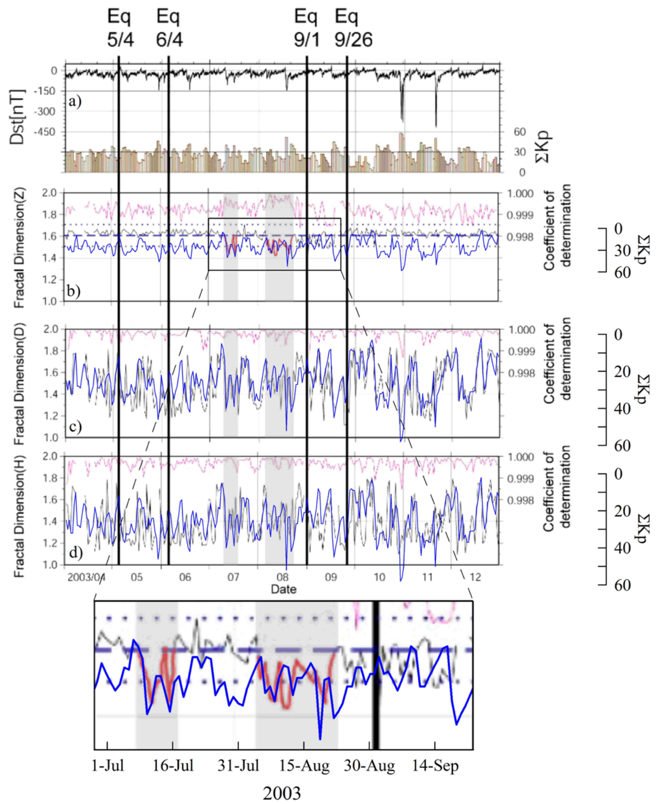

Fig. 1. A reproduction of Fig. 3 by Ida et al. (2012). Note that in the original figure panels **(a)** and **(c)** are horizontally shifted by about 1 day with respect to panels **(b)** and **(d)**. **(a)** denotes geomagnetic indices Dst and ΣKp time series. **(b)**, **(c)**, and **(d)** indicate fractal dimension daily values of the geomagnetic field components Z, D, and H, respectively. Vertical black lines refer to the $M_\mathrm{w} > 5$ earthquakes of 2003. Red lines highlight the pre-earthquake decreases of the fractal dimension of the Z component claimed to have a seismogenic origin by Ida et al. (2012). ΣKp index time series has been superimposed onto panels **(b)**, **(c)**, and **(d)**. An enlarged view of the presumed seismogenic fractal anomalies is shown on the bottom of the figure. See text for details.

et al. (2012), the fractal dimension decreases that occurred in July–August 2003 were related to the 1 September 2003 $M_\mathrm{w} = 5.7$ earthquake, whereas the January 2004 decrease was induced by a sharp variation (geomagnetic storm) in geomagnetic activity. With regards to the third decrease of June 2005, they did not come to a definitive conclusion. We would like to stress that in Fig. 2 by Ida et al. (2012) we can see similar decreases in the fractal dimension of the Z component during the periods July–September 2005 and May–September 2006 as well.

In our opinion, the only argument that might support the hypothesis that the fractal dimension decreases that occurred in July–August 2003 had a seismogenic origin is that they were observed close to the time of September 2003 earthquakes. However, this does not mean that they undoubtedly came from seismogenic sources. We think that Ida et al. (2012) underestimated the influence of the geomagnetic activity. The solar-wind–magnetosphere interactions and the ionosphere–magnetosphere coupling are the main sources of ULF signals. Therefore, as emphasized by Ida et al. (2012), any magnetic fields originating in the earth's crust must necessarily differ from the ULF magnetic signals of external origin. Figure 1 shows the findings of Ida et al. (2012). First of all, the reason for the lack of similar fractal decreases before 4 May and 5 June earthquakes is not clear. The 4 May earthquake was the closest and the largest earthquake that occurred during 2003 near the Kashi magnetometer station (see Fig. 1 by Ida et al., 2012). Secondly, the authors reported fractal dimension *decreases*, which is contrary to the papers cited in support of their claims that document *increases* of the fractal dimension. The authors' explanation that the preparation process of earthquakes sometimes induces increases, and at other times induces decreases in the fractal dimension of the geomagnetic field components, was speculative.

In Fig. 1 the geomagnetic ΣKp index time series is superimposed onto the original view. As expected, we find a strong inverse correlation between the geomagnetic activity level and the fractal dimension behavior of the geomagnetic field horizontal components H and D. This inverse correlation shows that the fractal dimension of the horizontal components does not simply fluctuate as suggested by Ida et al. (2012). Thus, we find that normal geomagnetic activity has a significant effect on the fractal dimension of geomagnetic field components, in addition to just geomagnetic storms as discussed by Ida et al. (2012). More precisely, a decrease of the geomagnetic activity (which induces a decrease of the ΣKp index) means that the magnetosphere evolves toward a lower degree of organization (Balasis et al., 2009). Thus the fractal dimension of the geomagnetic field increases. On the contrary, an increase of the geomagnetic activity means that the magnetosphere evolves towards a higher degree of organization. Therefore, the fractal dimension decreases. Obviously, we should not always expect a strict correlation between ΣKp and the fractal characteristics of the geomagnetic field, since the geomagnetic index is representative of globally averaged geomagnetic field disturbances. Looking at Fig. 1 we can see a good inverse correlation between the fractal dimension of the Z component and ΣKp during the period in which the presumed magnetic precursors occurred (see the enlarged view shown in Fig. 1). We also note that during the presumed precursory anomalies the variations in the fractal dimension of the Z component are similar to the variations in horizontal H and D components (refer to the shaded areas in Fig. 1). Thus, there is strong evidence that the fractal features simultaneously present in all the components of the geomagnetic field have a magnetospheric origin.

In addition, we digitalized the fractal dimension of the Z component from the original figure. In Fig. 2 we show the scatterplot of ΣKp and the fractal dimension of the Z component. We note that in the periods 7 to 17 July and 4 to 18 August, during which the presumed precursors were claimed to have occurred, ΣKp and the fractal dimension of the Z component have good inverse linear correlations. The value of the correlation coefficient is −0.74 for the period 7 to 17 July 2003 and −0.57 for the period 4 to 18 August 2003. In the latter case, the correlation coefficient rises to −0.77 if we consider only the first week from 4 to 11 August 2003. We know that the number of the samples is a bit small from a statistical point of view, but the small number of points used to calculate the two linear relationships is related to the short time duration of the presumed precursors. Conversely, as it is also evident in Fig. 1, during the remaining period of time, in which the fractal dimension is on average equal to 1.61, the two quantities are uncorrelated. This lack of correlation can be easily explained since the Z component is only weakly influenced by ULF signals induced by solar-wind–magnetosphere and magnetosphere–ionosphere interactions. Masci and Di Persio (2012) have shown that, while the horizontal components H and D have a strong similarity in the fractal time series, the Z component only sometimes (when it is more influenced by geomagnetic activity) shows the same fractal features of the other two components (see Fig. 4 by Masci and Di Persio, 2012). Bearing in mind these considerations, we should not expect a strong correlation between ΣKp and the fractal dimension of the Z component for a long time-series duration. On the other hand, if we find a close correspondence between ΣKp and geomagnetic fractal dimensions, we can minimize any possible influence of seismogenic sources, since these changes are very likely part of the normal global magnetic field variations driven by solar–terrestrial interaction. In summary, there is strong evidence that the fractal anomalies documented by Ida et al. (2012) are part of the normal geomagnetic activity rather than induced by seismic activity.

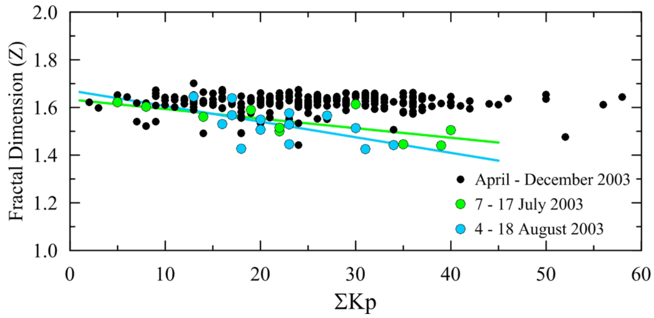

Fig. 2. Scatterplot of ΣKp and the fractal dimension of the geomagnetic field Z component during the entire period reported in Fig. 1 (black dots) and during the two periods in which the presumed precursors occurred. See text for details.

In a previous paper (Ida et al., 2008), the authors documented an increase in the ULF magnetic polarization ratio just before the 1 September 2003 earthquake. According to Ida et al. (2012), the common results shown by two different methods (fractal analysis and polarization ratio) confirmed the seismogenic origin of the ULF emission that occurred before the 1 September earthquake. We would like to stress that different analyses of the same dataset did not definitively confirm the origin of presumed seismogenic anomalies. Moreover, any potential earthquake precursor should be validated by means of other independent geophysical data. The polarization ratio is defined as the ratio between the integrated power, in a fixed range of frequency, of the vertical component Z and one of the horizontal components (H and D) of the geomagnetic field (i.e., Z/H and Z/D). To be more precise, Ida et al. (2008) performed an improved polarization ratio analysis. Refer to their paper for details. However, the reviews by Masci (2011, 2012a, b) and Thomas et al. (2009b) have shown that the magnetic polarization ratio is not a good indicator of precursors of pending earthquakes. They have clearly demonstrated that the variations of the magnetic polarization ratio that occurred prior to many strong earthquakes were induced by changes in geomagnetic activity and not related to the seismic activity. In our opinion, our findings do not support the idea that the polarization ratio increase documented by Ida et al. (2008) had a seismogenic origin. Namely, here it has been shown that the fractal dimension decreases that occurred in the Z component of the geomagnetic field before the 1 September 2003 earthquake were caused by an increase of normal geomagnetic activity on this component. Moreover, although only the Z component fractal dimension decreases, it otherwise varies much like the H and D component fractal dimensions. Since these variations of the fractal dimension are strongly correlated with ΣKp (see the shaded areas in Fig. 1), they most likely have a magnetospheric origin. The increase of ULF disturbances in the Z component without a corresponding increase in the horizontal components induces an increase in the ratios Z/H and Z/D. This could explain the polarization ratio enhancement documented by Ida et al. (2008) before the 1 September 2003 earthquake. More detailed investigations cannot be performed because Fig. 3 by Ida et al. (2008), in which the authors reported their results, is lacking in details.

3 Conclusions

In this paper we have shown that the studies by Ida et al. (2008, 2012) have not documented a strong evidence of seismogenic magnetic anomalies before the China earthquake of 1 September 2003, but in our opinion the authors have shown only variations of parameters (fractal dimension and polarization ratio) of the geomagnetic field that were part of normal geomagnetic activity driven by solar–terrestrial interactions. Consequently, short-term earthquake prediction based on these precursors, which we have shown to be unreliable, would be highly vulnerable to false alarms, and the possible development of prediction capabilities would be adversely affected.

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